Low-Loss, Low-Noise, Crystalline and Amorphous Silicon Dielectrics for Superconducting Microstriplines and Kinetic Inductance Detector Capacitors

Completed Technology Project (2017 - 2020)

Project Introduction

Prospective future PCOS (Inflation Probe) and COR (Origins Space Telescope, FIR Interferometer) missions require large arrays of highly sensitive millimeter-wave and submillimeter (mm/submm) detectors, including spectroscopic detectors. A number of technology developments in superconducting sensors for these applications require low-loss dielectric thin films. Examples include: Microstrip-coupled superconducting mm/submm detectors, which rely on superconductor-dielectric-superconductor microstrip transmission line to transmit optical power from a coherent reception element (feed horn, lens coupled antenna, phased-array antenna) to detectors; Superconducting spectrometers (SuperSpec, TIME, MicroSpec), which use such microstrip to route optical power to detectors and to define spectral channels; Kinetic inductance detectors (KIDs), which use capacitors. In the above, the dielectric loss, quantified by the loss tangent (tan delta), is critical: it determines the optical loss in the microstrip, the resolution of spectral channels, and the two-level-system (TLS) dielectric fluctuation noise of the KID capacitor. Currently, the amorphous dielectrics SiO_2 and SiNx are used because they are most convenient for fabrication. They have tan delta ~ 1e-3. This loss tangent is acceptable for microstripline but severely limits the possible architectures and spectral resolving power, and it is too large for KID capacitors. Lower loss dielectric would result in a quantum leap in capability, opening up design space heretofore inaccessible and enabling design innovations. Specific impacts on the above technologies would be: For phased-array antennas, lower optical loss would allow the detectors to be moved away from the antenna, allowing them to be shielded from absorption of light that has not been spatially or spectrally filtered and also obviating long wiring busses. More sophisticated antenna designs, such as multiscale antennas covering a decade of spectral bandwidth, could be entertained; For superconducting spectrometers, lower loss would improve the spectral resolution limit, Rmax = (1/tan delta), from 1e3 to 2e5, sufficient for resolved extragalactic mm/submm spectroscopy, where intrinsic line widths are dnu/nu ~ 1e-4 to 1e-3; For KIDs, the interdigitated capacitors (IDC) currently used could be replaced by parallel-plate capacitors 40 times smaller in area, presenting a number of advantages over IDCs in properties such as focal plane fill factor and mounting architecture, direct absorption, and inter-KID coupling. There exist two paths in the literature to lower loss: hydrogenated amorphous silicon (a-Si:H) and crystalline silicon (cSi). Crystalline silicon intrinsically has tan delta < 5e-6, 200 times lower than SiO_2 and SiNx. a-Si:H has been demonstrated with tan delta < 5e-5, not as good as cSi but still 20 times better than SiO_2 and SiNx. We will pursue the development of both options due their complementary advantages and challenges. While a process has already been demonstrated for 5 um cSi with delta < 1e-4 and consistent with other design/fabrication constraints, it has not been shown yet that this can be extended to more convenient 1 um and 2 um thicknesses. a-Si:H has been demonstrated to have tan delta < 1e-4, but the fabrication recipe is almost

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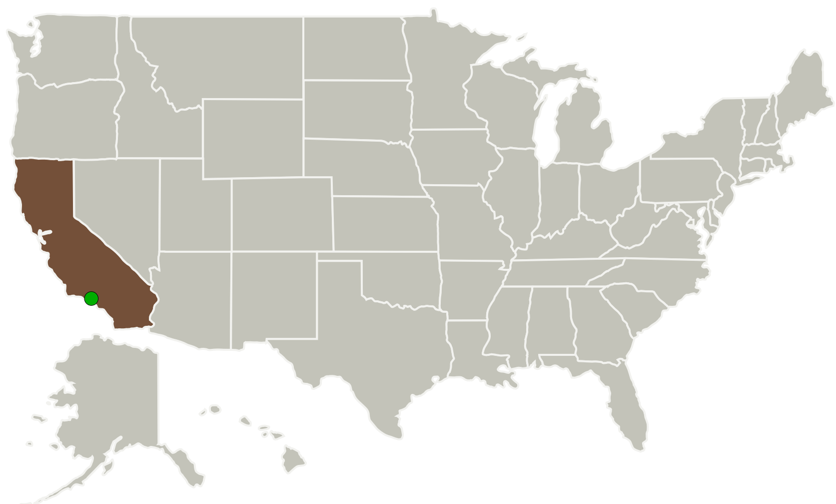
certainly machine-specific and may not be compatible with focal plane array fabrication due to adhesion or stress issues. Given the uncertainties and different constraints imposed by the two processes, it is sensible to pursue both. This development would contribute to filling the Critical Technology Gaps identified in the 2016 PCOS and COR Program Annual Technology Reports, specifically the PCOS "Advanced millimeter-wave focal plane arrays for CMB polarimetry" gap and the COR "Large-format, low-noise far-infrared and ultralow noise (FIR) direct detectors" and "Compact, Integrated Spectrometers for 100 to 1000 um" gaps.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
California Institute of Technology(CalTech)	Lead Organization	Academia	Pasadena, California
Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, California
University of California-Berkeley(Berkeley)	Supporting Organization	Academia	Berkeley, California

Organizational Responsibility

Responsible Mission Directorate:

Science Mission Directorate (SMD)

Lead Organization:

California Institute of Technology (CalTech)

Responsible Program:

Astrophysics Research and Analysis

Project Management

Program Director:

Michael A Garcia

Program Manager:

Dominic J Benford

Principal Investigator:

Sunil Golwala

Co-Investigators:

Benjamin Mazin
Elizabeth Hisserich
Andrew D Beyer
Henry G Leduc
Peter K Day

Technology Areas

Primary:

- TX08 Sensors and Instruments

Continued on following page.

Primary U.S. Work Locations

California

Technology Areas *(cont.)*

- └ TX08.1 Remote Sensing Instruments/Sensors
  - └ TX08.1.1 Detectors and Focal Planes

Target Destination

Outside the Solar System